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Petrophysical properties of Quaternary lavas of Spitsbergen

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Abstract. The chemical and mineralogical composition, structure and petrophysical properties of volcanic rocks, composing three Quaternary volcanoes of Spitsbergen island – Sverrefjellet, Halvdanpiggen and Sigurdfjellet – have been studied and compared. The sharp tendency of basalts elastic properties' change in a row of volcanism "rejuvenation" – Sigurdfjellet — Halvdanpiggen — Sverrefjellet has been obtained. The same links between petrophysical characteristics have been defined for all studied volcanoes. This paper reveals the benefits of petrophysical properties — density (ρ), porosity (P), velocity of longitudinal waves (V_p), strength (R_c) – for the definition of lava flows within basaltic outcrops. The petrophysical peculiarities of Spitsbergen basalts have been shown in comparison with basalts from various tectonic unites of the Earth — rifts, island arcs and foldbelts.

1. Introduction

Spitsbergen is situated far north from Norway in the Arctic Ocean and represents the northern edge of the Barence plate. The post-Paleozoic activity of the Svalbard area is divided into three groups [*Harland,* 1973; *Kovaleva and Burov,* 1976; *Prestvic,* 1977]. Each group is characterized by some chemical and petrographical peculiarities (Table 1).

1. *Basic lavas and dolerites of Mesozoic age.* The Mesozoic volcanic activity is developed on both sides of Storfjorden and Hinlopenstretet and on King Karls Land. The lavas are only slightly studied because the region of their occurrence (King Karls Land) is difficult of access. Chemical likeness is defined for both facies.

2. *Plateau lavas of Cenozoic age.* They are capping some of the mountains in the Andre Land (east of the Woodfjorden). Lavas are olivine-basalts with massive or amygdaloidal structure, ophitic or poikilophitic texture.

3. *Quaternary volcanic rocks.* Quaternary volcanoes of Spitsbergen were discovered and studied by A. Hoel and O. Holtedahl in 1911. These volcanoes form three centers — Sigurdfjellet, Halvdanpiggen and Sverrefjellet located along submeridional fault zone in the northwest part of Spitsbergen. The fault zone is the west part of Devonian graben, complicated by the Alpine tectonic movements. Quaternary volcanism of Spitsbergen assumed to be connected with the opening of the Eurasian and Norwegian-Greenlandian basins [*Vogt et al.,* 1978] and reactivation of "Yermak hot spot" [*Prestvic,* 1977]. Volcanoes get younger towards north in the following sequence: Sigurdfjiellet, Halvdanpiggen and Sverrefjiellet [*Yevdokimov,* 2000]. Sverrefjellet and Sigurdfjellet are formed as a result of fissure eruption while Halvdanpiggen is assumed a central neck with several satellite lava-flows.

Chemical composition, petrographical peculiarities and especially xenoliths of Spitsbergen basalts have been studied before and described in the papers [*Yevdokimov,* 2000; *Genshaft et al.,* 1992; *Kopuylova et al.,* 1996; *Kovaleva and Burov,* 1976; *Prestvic,* 1977; *Tebenkov and Sirotkin,* 1990] while petrophysical properties have not been considered. Only one paper [*Kurinin,* 1965] elucidates the properties of Spitsbergen rocks' such as density and magnetic characteristics. However basalts are not considered in that paper.

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Table 1. The average chemical composition of Spitsbergen basalts [*Kovaleva and Burov,* 1976]

Oxides, %	Dolerites Mz	Basalts Mz	Plateau basalts Cz	Basalts Q
SiO_2	49.4	49.1	49.3	45.8
TiO_2	3.5	1.5	1.3	2.7
Al_2O_3	13.4	13.7	15.7	13.9
Fe_2O_3	4.6	4.4	3.7	3.1
FeO	10.3	10.9	7.6	8.0
MgO	5.6	6.0	9.7	9.5
CaO	9.6	11.4	8.3	8.8
Na_2O	2.3	2.6	3.2	4.6
K_2O	0.8	0.3	0.7	2.4
LOI	1.3 (0.9–2.6)		1.8 (0.2–7.2)	1.2 (0.8–2.2)

Petrophysical properties are represented by the set of parameters: physical (density, elastic, thermal, magnetic, electrical) and mechanical ones, which are defined by laboratory methods. Petrophysical properties depend on the petrographical peculiarities of rock among which are the chemical and mineral composition, structure and texture, and reflect the conditions of rock formation and post-genetic transformations. It is important that petrophysical information is quantitative, and is based on a set of numeric parameters. This allows to make a statistical calculation of data, to compare the results obtained, to characterize rocks groups by numeric values, to consider dynamic of rocks properties' changes in time and space. Thus, petrophysical analysis brings the additional information, which can be used for recognizing of rocks' petrotypes. Petrophysical analysis allows to characterize a behavior of rocks under tectonic processes, collector and orehosting properties, being one of the methods for deciding various geological targets. Knowledge of the petrophysical properties of rocks is necessary for interpretation of geophysical log and numerical modeling as well.

Present paper describes and analyses the petrophysical properties of lavas of three Quaternary volcanoes – Sigurdfjellet (26 samples), Halvdanpiggen (18 samples) and Sverrefjellet (76 samples) along with their chemical and mineral composition. The study is based on the rocks material sampled by D. Dashevskaya and M. Kopylova during the field works of the Scientific Research Institute "VNIIOceanology" in 1988–1990.

2. Methods of investigation

Petrophysical analysis was included the following determinations: bulk density (ρ), specific density (ρ_s) water absorption (W), total porosity (P), velocity of longitudinal waves in dry (V_p) and water-saturated (V_{pw}) conditions, velocity of transversal waves (V_s), modulus of elongation (E), strength (axial compression) (R_c), magnetic susceptibility (χ). All parameters were defined according to the standard methods [*Sergeev,* 1984].

Bulk density was defined by the standard measurement of a size and mass of the sample of the right geometric shape.

Specific density (mineral density of rock) is the density of solid, mineral particles and crystals of rock, excluded the pores, fractures and water. Specific density was defined by exclusive device ELA [*Kalachev et al.,* 1997]. The main principle of this device is the Boil-Moriotte law.

Then, the total porosity of rock was calculated by following equation:

$$P = \{(\rho - \rho_s)/\rho_s\} \times 100 \ , \qquad (1)$$

where ρ – bulk density, ρ_s – specific density.

Water absorption was determined by the following equation:

$$W = \{(m_2 - m_1)/m_1\} \times 100 \ , \qquad (2)$$

where m_1 – mass of dry sample, m_2 – mass of water saturated sample after 7 days keeping in water.

Elastic characteristics (velocity of longitudinal and transversal waves) were defined by ultrasonic method (DUK-6B – frequency 700 kHz and US-13 I – frequency 1 MHz).

These characteristics were used for the calculation of the elongation modulus:

$$E = 2V_s^2\rho(1 + \mu) \ , \qquad (3)$$

where μ is the Poisson ratio and

$$\mu = (V_p^2 - 2V_s^2)/\{2(V_p^2 - V_s^2)\} \ . \qquad (4)$$

Velocity of longitudinal waves was determined for the dry and water saturated samples. By the difference of those values coefficient, Q_{vp} was calculated:

$$Q_{vp} = \{(V_{pw} - V_p)/V_p\} \times 100 \ , \qquad (5)$$

where V_p – velocity of longitudinal waves for dry samples, V_{pw} – velocity of longitudinal waves for water-saturated samples.

Petrophysical parameter Q_{vp} helps to study characteristic features of rocks pore-space structure. The previous study of a large volcanic rocks collection (5000 samples of various age from different tectonic environments of the Earth) was defined some peculiarities of Q_{vp} changes [*Ladygin and Frolova,* 2001]. As a rule the high value Q_{vp} indicates the existence

Table 2. The average chemical composition of the studied basalts

	SiO_2	TiO_2	Al_2O_3	FeO	Fe_2O_3	MgO	CaO	Na_2O	K_2O	H^+	H^-	Number of samples
Halvdanpiggen												
Central neck	45.9	1.89	14.92	4.37	6.65	10.74	8.87	3.91	1.84	2.3	0.8	2
Satellite lavas	44.3	2.01	14.34	3.30	7.29	11.29	8.26	3.85	1.72	2.3	0.4	5
Sigurdfjellet												
I outcrop	43.2	2.45	15.0	3.11	8.16	11.2	8.40	3.32	1.51	2.40	0.35	3
II outcrop	43.5	2.6	14.7	2.73	8.36	10.8	9.17	3.75	1.72	1.20	0.24	2
Sverrefjellet												
	44.59	2.61	14.41	2.71	8.04	9.77	9.0	4.44	2.06	1.37	0.23	22

of microfractures and open pores within the rock. Value about nought is the evidence of dense structure with small pores. Negative value indicates of clay or other loose second minerals, which recompact contacts within rocks under water saturation. Q_{vp} parameter gradually decreases through time from 30–40% (mounting to 100% in recent basalts) to 0% and negative values in old rocks. In the same direction the dispersion of Q_{vp} parameter decreases.

Strength (axial compression) was defined by the use of German hydraulic press CDM-10/91 for plug samples (H = D = 40 mm).

Magnetic properties of rocks were characterized by magnetic susceptibility, determined by the use the Magnetic Susceptibility Meter (Kappameter KT-5).

Petrophysical properties were analyzed along with composition and structure of the rocks. All samples were studied in thin sections. X-ray analysis, scanning microscopy and microprobe were made for portion of the samples. Correlation relationships between petrophysical characteristics were studied using software "Statistics" and equations of regression were calculated.

3. Petrographical Description and Petrophysical Characteristics of Basaltic Rocks From Three Quaternary Volcanoes

Short petrographical description and petrophysical characteristics of basaltic rocks are discussed below.

3.1. Sigurdfjellet

Sigurdfjellet is the ridge of 4.5 km long composing of pyroclastic deposits with rare lava flows. This is a fissure-type volcano with multistages history of development [*Yevdokimov,* 2000]. Lavas are characterized by low content of SiO_2 (43.35%) and refered to the subalkaline picrites [*Yevdokimov,* 2000]. Sigurdfjellet's lavas distinguish as well from two other studied volcanoes by higher content of Fe_2O_3 (8.23%), and lower content of alkaline (Na_2O+K_2O=5.1%) (Table 2).

Basalts have porphyritic texture. Phenocrysts are composed of olivine and titan-augite, rarely of orthorhombic pyroxene and plagioclase. Two groups of phenocrystals are distinguished by size: large and fine. The large phenocrysts have a zonal sructure. The texture of the matrix is a mainly hyalopilitic (content of volcanic glass is about 50%), rarely intersertal. Matrix is composed of volcanic brown, light-brown color glass, plagioclase microlites (0.005–0.1 mm), and isomorphic microcrystals of titanomagnetite (0.001–0.07 mm). Titanomagnetite forms an irregular, forming accumulations of 15–25 grains. In two samples (3–10 and 3–12) a lot of needle crystals of ilmenite occur (up to 0.02 mm length).

Basalts have different types of structure: massive, porous and amygdaloidal. The last one has been formed as a result of pores' filling by iddingsite. Fine pores are filled totally while large pores partially.

Lavas were sampled from two outcrops. Petrophysical properties of lavas from these outcrops are distinguished from each other. More porous basalts (I outcrop) have low values of bulk density, velocity of longitudinal waves and strength (Table 3). Specific density and magnetic susceptibility are the same for all basalts that is the result of the similar chemical composition of lavas (Table 2).

3.2. Halvdanpiggen

Halvdanpiggen has the large diameter (120–200 m) central neck with several satellite lava flows located of 500 m, 1000 m and 1500 m faraway. Three stages of eruption are observed during the evolution of Halvdanpiggen. The first stage resulted in formation of porous basalts. Vent agglomerates were formed during the second stage. The eruption was finished by formation of the massive basalts containing

Table 3. Petrophysical properties of the studied basalts

	ρ, g/cm^3	ρ_s, g/cm^3	P, %	W, %	V_p, km/sec	V_s, km/sec	Q_{vp}, %	R_c, MPa	$\chi\times10^{-3}$, SI	Number of samples
Halvdanpiggen										
Central neck	2.7 2.57–2.81	3.02	9.5 7.1–14.2	1.65 1.0–2.2	5.35 4.65–5.95	3.1	−2 −13–7	216 151–284	17 12–24	9
Satellite lavas	2.9 2.77–2.99	3.08	5.8 2.9–10.1	0.5 0.2–1.2	5.5 4.65–6.0	3.4	4 −8–19	282 171–454	28 17–35	10 10
Sigurdfjellet										
I	2.51 2.43–2.6	3.01	16.6 14–19	 —	5.1 4.3–5.45	3.15 —	−2 −9–10	129 101–159	6.5 2–19	7
II	2.87 2.59–2.96	3.03	5.2 2.6–14.5	—	5.85 4.65–6.3	3.45	2.9 −15–13	251 97–348	7 2–15	19
Sverrefjellet										
	2.45 1.84–2.88	3.01	18.8 4–38	2.0 0.4–10	5.05 2.8–6.0	3.05 2.0–3.6	6 −13–33	143 14–342	7.4 2–15.5	76

In numerator – average value of parameter, in denominator – min and max values.

a lot of nodules (30%) at the last stage. Porous basalts were sampled from the central neck (samples no. 15), while massive basalts were taken from satellites (samples no. 17–20).

In comparison with Sigurdfjellet and Sverrefjellet lavas of Halvdanpiggen are distinguished by higher contents of SiO_2 (44.75%) and FeO (3.61%), and lower contents of Fe_2O_3 (7.11%), CaO (8.43%) and TiO_2 (1.98%).

Some petrographical and petrophysical differences are observed between the basalts of the central neck and satellites. Table 2 shows difference in the chemical composition. Basalts of the central neck are formed from more acid and higher alkaline basaltic lava with lower content of TiO_2 and Fe_2O_3. Lavas of satellites should be attributed to ultrabasites (SiO_2 <45%).

Lavas of the main neck and the satellites are differed by structure and secondary minerals type and chemistry, resulting in petrophysical properties (Table 3). Lavas from the central neck are characterized by porphyritic texture. Phenocrysts are composed of olivine (Fo_{80-85}) and titanaugite, rarely of orthopyroxene (enstatite) and plagioclase (andesine-labrador) having various length — from 0.1 to 2–4 mm (mainly 0.2–1 mm). Large crystals are of irregular shape, while middle and fine crystals have regular crystallographic shape. Content of phenocrysts varies from 10–15% to 20–25%. Large xenocrystalls (5–7 mm) represented by fractured growth of olivine, olivine-pyroxene occur within basalts as well. These xenocrystalls are responsible for unexpected changes of petrophysical characteristics.

The matrix is microcrystalline and composed of plagioclase and rarely pyroxene microlites (0.02–0.15 mm, 0.05 mm is the most common) with volcanic glass. Contents of volcanic glass varies from 5–7 up to 50–60%. According to the increase of volcanic glass the structure of matrix changes: microdoleritic – intersertal (and microlitic) — hyalopilitic. The intersertal structure is the most common and is characterized by 10–20% of volcanic glass. In the matrix a large number of isometric crystals of titanomagnetite are observed (0.002–0.01 mm). According to microscopic test, 120–400 grains were observed per the area 0.27 mm^2.

Basalts are fresh, with the exception of olivine crystals, which are partially substituted by iddingsite (Table 4) beginning from edges.

Initially basalts forming central neck had porous structure. Size of pores varied from 0.05 up to 5–7 mm. As a result of activity of the post-magmatic thermal fluids, majority of pores was partially filled by calcite and iddingsite-like

Table 4. The chemical composition of secondary minerals (by microprobe)

	SiO_2	Al_2O_3	Fe_2O_3 + FeO	MgO	CaO	Na_2O	K_2O	TiO_2
In amygdal	42–53	7–18	19–42	2–4.8	3–4.8	0–1	0.3–1.1	0–0.16
By olivin	43.9–45.9	9.8–15.3	30.2–37.7	1.7–1.9	5.3–5.4	0.02–0.19	0.1–0.3	0.07–0.19

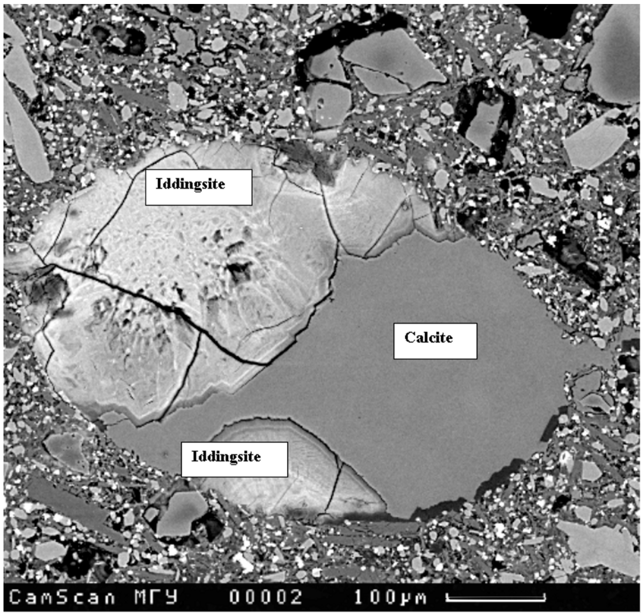

Figure 1. Photo by scanning microscope of Halvdanpiggen basalt (sample 15-8). Iddingsite-like mineral and calcite filling the pore.

mineral (Figure 1, Table 4). Now basalts are characterized by porous or amygdaloidal structure.

An incomplete pores filling by secondary minerals is responsible for "middle" value of density of basalts (ρ = 2.57–2.81 g/cm^3). Velocities of longitudinal waves vary from 4.65 to 5.95 km/sec (average V_p = 5.35 km/sec) and are not changed during saturation by water (Q_{vp} = 2%). Some samples containing a lot of elongated schlierens are characterized by lower strength (150–185 MPa). The average magnetic susceptibility of basalts is about 17$\times$10^{-3} SI.

Basalts of satellites have porphyritic texture and the similar mineral assemblage. The distinguishing features are lighter volcanic glass and higher degree of crystallization. Microlites of the matrix — pyroxenes as well as plagioclases — have more distinct sharp and mount to 0.1 mm size. Basalts have massive structure results in high density (ρ = 2.87–2.99 g/cm^3), V_p (5.5 km/sec) and strength (R_c = 282 MPa). Two samples have porous structure partially filling by iddingsite that result in density (2.77–2.81 g/cm^3) and strength (R_c = 171–173 MPa) decrease.

Magnetic susceptibility of satellites ($\sim$30$\times$10^{-3} SI) is much higher in comparison with central neck ($\sim$15–20$\times$10^{-3} SI). The reason is oxidation of titanomagnetite in central neck.

3.3. Sverrrefjellet

Sverrefjellet is stratovolcano of 506 m height and 3 km in diameter located in the Bockfjorden. The volcano is in close association with large submeridional fault, shearing Devonian graben from the east and metamorphic succession Hecla-Hoek from the west. Chemical composition of Sverrefjellet lavas are distinguished by higher contents of alkaline ($Na_2O + K_2O$ = 6.5%), CaO (9%), TiO_2 (2.61%), and lower contents of FeO (2.71%) and MgO (9.77%) (Table 2).

Basalts outcrops composing of pillow-lava flows (4–5 m thickness) with a great amount of xenoliths (20–50% in the bottom of the flow, 2–8% in the top of the flow) are found at all slopes of volcano, with the exception of southern and west-southern slopes.

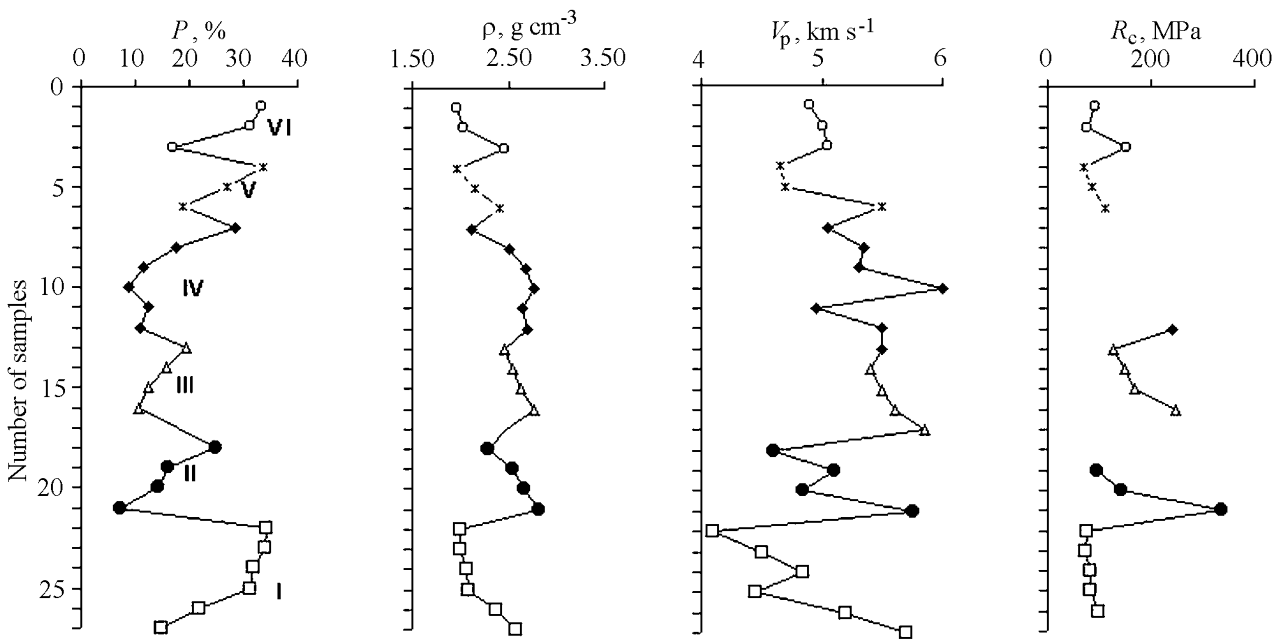

Figure 2. The change of petrophysical properties along geological section. Lava flows: I, II,...

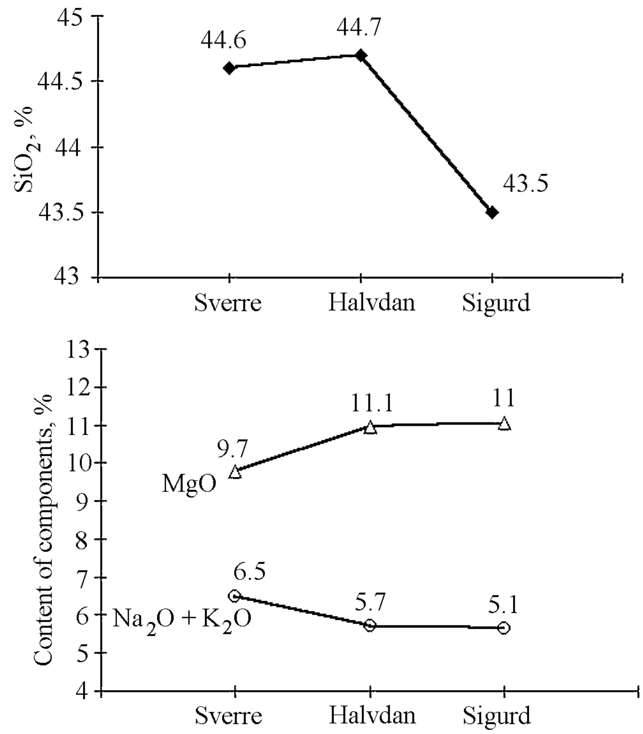

Figure 3. The comparison of average chemical composition (SiO_2, MgO, Na_2O+K_2O) of studied basalts.

Basalts outcrop located at the lower part of east slope of the volcano was studied in detail. Sampling was made in 1–1.5 m step, and 27 samples were studied. Basalts have porphyritic texture with olivine and pyroxene phenocrysts. Matrix texture is hyalopilitic with pyroxene and plagioclase microlites. The average values of petrophysical parameters are shown in Table 3.

Basalts outcrop can be divided into 6 lava-flow in the base of the alternation of porous and massive basalts and through the stepped change of petrophysical properties. (Figure 2). Within each of the lava-flow porosity increases from the bottom to the top: I – 15–34%, II – 7–25%, III – 10–19%, IV – 10–28%, V – 18–34%, VI – 17–33%. Stepped change of velocity of longitudinal waves and strength is observed as well accordingly to lava-flows. V_p changes: I – 5.7–4.1 km/sec, II – 5.75–4.6 km/sec, III – 5.85–5.5 km/sec, IV – 5.5–5.0 km/sec, V – 5.5–4.65 km/sec, VI – 5.05–4.9 km/sec. Strength R_c changes: I – 100–75 MPa, II – 340–95 MPa, III – 250–125 MPa, IV – 250–? MPa, V – 110–70 MPa, VI – 150–90 MPa.

Magnetic susceptibility of basalts varies in a range $2–15\times10^{-3}$ SI without any correlation between lava-flow structure and magnetic properties. III and VI lava-flows are characterized by the highest magnetic susceptibility, while IV lava-flow has the lowest one.

Rock outcrop of the same basalts located of 100 m far away was studied. Petrophysical analysis shows that the most massive basalts (ρ = 2.64 g/cm^3) are found in the bottom of the outcrop. These basalts have the next petrophysical properties: V_p = 5.85 km/sec, R_c = 167 MPa, W = 0.8%. Upward to the geological section basalts become more porous (ρ = 2.4–2.42 g/cm^3), results in water absorption increases (W = 2–2.3%) while velocity of longitudinal waves (V_p = 4.8–5.4 km/sec), strength (R_c = 125–129 MPa) decrease. High-porous basalts (ρ = 2.08–2.11 g/cm^3) having high water absorbtion (W = 3.3%) and low velocity of longitudinal waves (V_p = 4–4.65 km/sec) and strength (R_c = 71–90 MPa) are observed above. Other lava-flow is assumed above since density (ρ = 2.2–2.32 g/cm^3) and V_p (4.45–4.95 km/sec) increase sharply and water absorption decreases (W = 2.2%).

Thus, petrophysical characteristics are useful for geological section investigation, definition of lava-flows within basaltic outcrops and for study of lava-flows' structure. Among all Sverrevjellet basalts two samples are found having vitrophyric texture. Content of the glass having sideromelane habit is about 90%. These rocks are characterized by the lowest physical-mechanical properties: ρ = 2.03 g/cm^3, V_p = 3.2 km/sec, R_c = 38 MPa, while have the highest magnetic susceptibility ($\chi = 15\times10^{-3}$ SI).

4. Discussion

Lavas of three studied Quaternary volcanoes are characterized by rather similar chemical composition. The lavas are of alkaline composition with low SiO_2 varying from 42.86 to 48.56% (average value 44.62%), that is close to the boundary between basic and ultrabasic lavas. Increase of SiO_2 and alkalinity as well as decrease of MgO are observed towards north according to the "rejuvenation" of volcanoes (Figure 3). The common petrographical feature of basalts of all volcanoes are porphyritic texture and mainly hyalopilitic (rarely vitrophiric or intersertal) texture of matrix. The matrix is composed on 65–75% (rarely 85%) of light, half-translucenting, pink-brown and brown volcanic glass containing ore minerals. The structure of the basalts are massive or porous, rarely amygdaloidal.

As a result of the similar chemical composition all basalts are characterized by equal specific density ($\rho_s \sim$ 3.01–3.03 g/cm^3), while other petrophysical characteristics are different. The Sverrefjellet basalts were formed from the most gas-containing lavas (P = 19%) resulted in their density (ρ = 2.45 g/cm^3), and are characterized by the minimum values of elastic (V_p = 5.05 km/sec, $E = 60\times10^3$ MPa) and mechanical (R_c = 138 MPa) parameters. Comparatively low properties values, especially V_p, and high Q_{Vp}-parameter (6%) confirm the suggestion about the youngest age of Sverre volcano. Basalts of Halvdanpiggen and Sigurdfjellet are characterized by rather similar density (ρ: 2.8 and 2.76 g/cm^3), porosity (P: 8.1 and 8.5%), velocity (V_p: 5.45 and 5.55 km/sec), strength (R_c: 252 and 214 MPa) and modulus of elongation (E: 72 and 76×10^3 MPa) (Figure 4).

Basalts of Sverrefjellet and Sigurdfjellet have similar low values of magnetic susceptibility while basalts of Halvdanpiggen are more magnetic.

The sharp tendency of some petrophysical properties changes was found according to the "rejuvenation" of studied volcanoes (Figure 4). Thus, in a sequence Sigurdfjellet – Halvdanpiggen – Sverrefjellet we established the stable decrease of velocity of longitudinal waves (5.55 – 5.45 – 5.05 km/sec), velocity of transversal waves (3.35 – 3.25 – 3.05 km/sec) and modulus of elongation (76 – 72 – 60×10^3 MPa). Values of Q_{vp}-parameter increase in the same sequence: −2%–1%–6%.

Overall to consider Quaternary volcanism of Spitsbergen, the similarity of lavas of three studied volcanoes by chemical and mineral composition and structure should be noted. This is suggested to be the result of similar conditions of formations: depth of magma chamber, dynamics of rising magma and crystallization. This explains the similar relationships between petrophysical parameters obtained for studied volcanoes: $\rho(P) - R_c$, $\rho(P) - V_p$.

Petrophysical peculiarities of subalkaline Quaternary basalts of Spitsbergen which belongs to modern platform, were revealed in comparison with Quaternary basalts from various regions and tectonic environments: active continental margins (island arcs type — Kuril-Kamchatskaya and New-Zealand island arcs), mid-oceanic ridges (Bouvet, Red Sea and Hess depression) and foldbelts (The Lesser Caucasus, Etna volcano). The relationships between petrophysical parameters were compared for different basalts collections. The comparison of relationships $\rho(P) - R_c$ shows that subalkaline basalts of Spitsbergen are close to tholeiitic rift basalts and are characterized by significantly higher strength (for the same porosity's value) in comparison with calc-alkaline basalts of island arcs and foldbelts (Figure 5). This is explained by particular high strength of homogeneous glassy matrix of Spitsbergen and confirms the conclusion obtained by geochemical data about the rapid magma rising form the depth without any transitional magma chambers [*Yevdokimov,* 2000]. The strength difference between basalts' groups increases along with the decrease of porosity, when the petrographical composition and structure become the main factors controlling properties. Thus, if $P \sim 30\%$ the difference is approximately 40–50 MPa and $P < 10\%$, the difference increases up to 100 MPa.

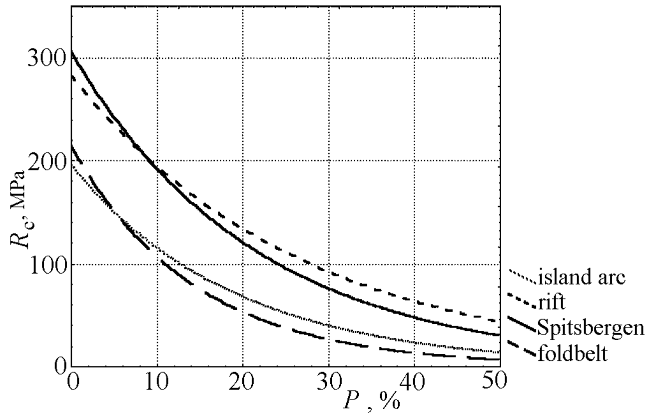

Figure 5. The diagram $P - R_c$ for basalts from the different tectonic environments of the Earth.

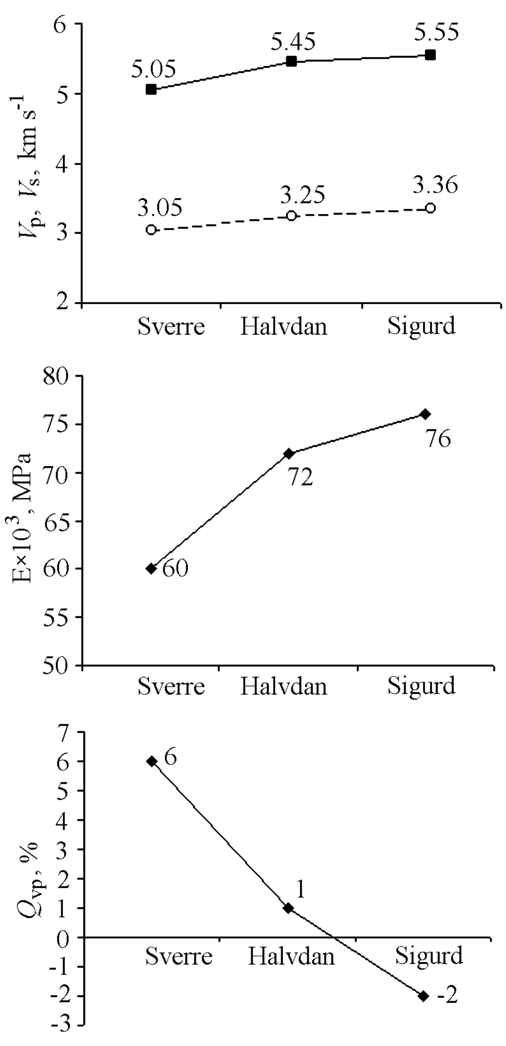

Figure 4. The comparison of average petrophysical parameters (V_p, V_s, E, Q_{vp}) for studied basalts.

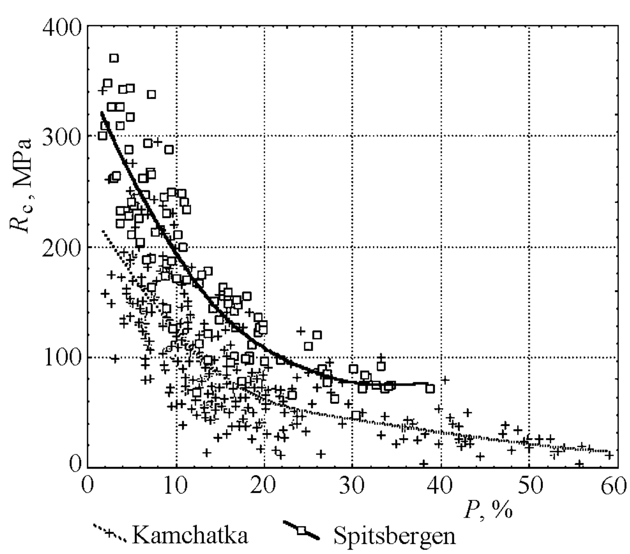

Figure 6. The diagram $P - R_c$ for hyalobasalts of Spitsbergen and Kamchatka Peninsula.

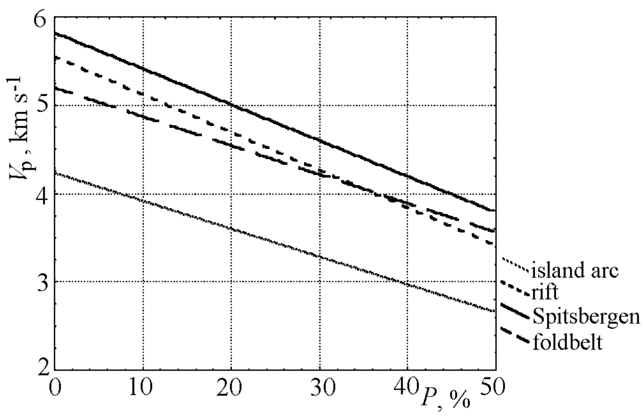

Figure 7. The diagram $P-V_p$ for basalts from the different tectonic environments of the Earth.

To confirm peculiar high strength properties of volcanic glass of Spitsbergen basalts, they are compared with Quaternary calc-alkalii hyalobasalts from Kamchatka, which by 50–70% consist of volcanic glass as well while were formed in rather different conditions (410 samples). The plot (Figure 6) sharply shows that the curve, describing relationship $P-R_c$ for Spitsbergen basalts is located higher than the curve characterizing basalts from Kamchatka. The difference becomes greater along with decrease of porosity.

The comparative analysis of relationship $P-V_p$ shows that for the same porosity value, V_p of Spitsergen basalts approximately by 0.2–0.3 km/sec higher than V_p of rift basalts, by 0.2–0.6 km/sec than V_p of foldbelt basalts and by 1.5 km/sec – than V_p of island arcs basalts (Figure 7). Thus, Spitsbergen basalts are characterized by the most "ridge" matrix in comparison with others basalts. Exception is porous ($P \sim 33$–38%) vitrophyric (90% volcanic glass) basalts of Sverre volcano. These basalts contain a large number of fine pores (size 0.01–0.2 mm, average size — 0.05 mm), results in V_p decrease down to 2.8–3.8 km/sec. The same by texture and structure basalts but having larger pores (0.5–3 mm) are characterized by $V_p \sim 4.6$–4.9 km/sec.

5. Conclusion

1. Lavas of three Quaternary volcanoes – Sigurdfjellet, Halvdanpiggen and Sverrefjellet are characterized by rather similar chemical and mineral composition (subalkaline with low SiO_2 content), although slight increase of SiO_2 and alkalinity as well as decrease of MgO are observed towards north according to the "rejuvenation" of volcanoes. Lavas have porphyritic texture, and mainly hyalopilitic texture of the matrix. Structures of the lavas are mainly porous and massive, rarely amygdaloidal.

2. As a result of the similar chemical composition all the basalts are characterized by equal specific density ($\rho_s \sim 3.01$–3.03 g/cm^3).

3. Other petrophysical characteristics of lavas of three volcanoes have some differences. The Sverrefjellet basalts are the most porous; result in the least dense, strong and "acoustically rigid". Basalts of Sigurdfjellet and Halvdanpiggen are characterized by rather similar petrophysical properties, which are higher in comparison with Sverrefjellet.

4. Acoustic and deformational characteristics of lavas decrease according to the "rejuvenation" of studied volcanoes in the sequence: Sigurdfjellet – Halvdanpiggen — Sverrefjellet.

5. Lavas of Sverrefjellet and Sigurdfjellet have similar low values of magnetic susceptibility, while Halvdanpiggen lavas have the highest magnetic susceptibility.

6. Petrophysical properties (ρ, P, V_p, R_c) can be effectively used for the determination of lava-flows within basalts outcrops and for investigation of their structure.

7. Three studied volcanoes are characterized by similar relationships $\rho(P)-R_c,\ \rho(P)-V_p$.

8. Spitsbergen basalts are distinguished from island arcs' and foldbelts' basalts by essential higher strength and sonic velocity; they are closed to rift basalts.

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